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For Pa

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HOME OFFICE

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SCIENTIFIC ADVISER'S BRANCH

CD/SA 116

RESEARCH ON BLAST EFFECTS IN TUNNELS

With Special Reference to the Use of London Tubes as Shelter

by F. H. Pavry

Summary and Conclusions

The use of the London tube railways as shelter from nuclear weapons raises many problems, and considerable discussion of some aspects has taken place from time to time. But - until the results of the research here described were available - no one was able to say with any certainty whether the tubes would provide relatively safe shelter or not.

This research, consisting of a series of model experiments, has demonstrated that the risk from blast in the tubes would be less than the risks above ground. The results are considered to be consistent enough to provide a good estimate of full-scale conditions, and reliable enough to be used as a basis for Home Office shelter policy regarding the London tube railways.

Introduction

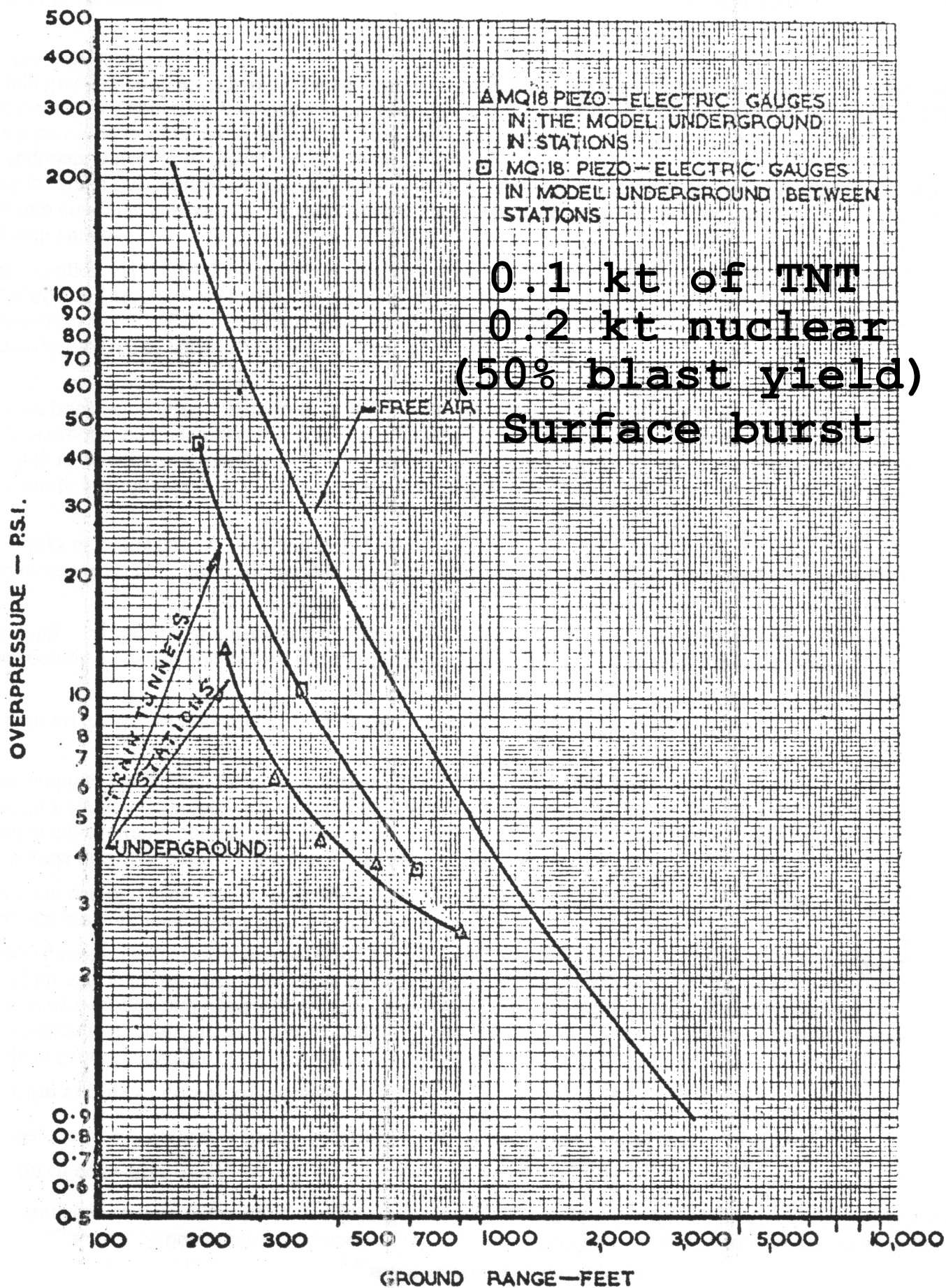
When the Advisory Group on Structural Research for Civil Defence was formed in 1957, the Chairman recommended that a study of the effects of blast on tunnels should be one of the main research projects. The relevant paragraphs of his proposals⁽¹⁾ for a research programme were:-

"In any consideration of tunnels as shelter the crucial problem is the entry of blast, either through existing openings or from a crater formed by a ground-burst bomb. It is particularly important to know if the collapse of a tunnel by earth shock would prevent the blast from entering it, and also whether the collapse would provide a seal against the entry of water from the crater. It is probable that some data could be derived from model experiments using H.E. charges. But it is for consideration whether the results would be so conclusive that the behaviour of full-size tunnels when damaged by megaton weapons could be forecast with the confidence that a major shelter programme would demand."

At the second meeting⁽²⁾ the Group agreed that model experiments with H.E. charges would be worthwhile, and that the Atomic Weapons Research Establishment (A.W.R.E.) should carry out this research, which has now been accepted by the Advisory Group as successfully completed. A summary record of the progress follows.

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100 ton TNT test on 1000 ft section of London Underground tube at Suffield, Alberta, 3 Aug 1961



Atomic Weapons Research Establishment, "1/40th Scale Experiment to Assess the Effect of Nuclear Blast on the London Underground System", Report AWRE-E2/62, 1962, Figure 30. (National Archives ES 3/57.)

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These trials are described in a preliminary report⁽⁵⁾ prepared for the Advisory Group by A.W.R.E. It was shown that the blast pressure inside a tunnel system, having openings at intervals to ground level, is less than the pressure at ground level at any distance from the explosion, by a factor of about 3. This reduction in pressure was apparently caused by the station entrances acting as expansion chambers. This observation was of outstanding significance to the consideration of London tubes as shelter.

All previous research on blast in tunnels - and a great amount of work was done on this in the last war - had been conducted with blast entering the open end of a tunnel without side openings. This research had shown that the blast, once it had got into a tunnel, tended to travel great distances without appreciable diminution. This had, therefore, led to the general belief that the London tubes could be death traps rather than shelters.

The more recent research here described showed for the first time that a person sheltering in a tube would be exposed to a blast pressure only about $\frac{1}{3}$ as great as he would be exposed to if he was above ground. (In addition, of course, he would be fully protected from fallout in the tube.)

In fact A.W.R.E. carried out two further tests, with more accurate scaling of station volumes based on more detailed information from the London Transport Executive. A full report on all four tests is in preparation.

These later tests showed that the pressure in station tunnels was only about $\frac{1}{6}$ th of the ground-level pressure, but that the reduction was not so great in the smaller-diameter train tunnels.

At this stage the Advisory Group were reasonably satisfied that this problem - of blast entry from stations - had been solved. But the other major question of blast entry direct from the crater remained in doubt, on account of the very small scale of the tests to date. Therefore, when the opportunity arose of testing at a really large scale at Suffield, Canada, it was naturally accepted.

Large-Scale Field Test ($\frac{1}{40}$) at Suffield, Alberta

The test is fully described in an A.W.R.E. report⁽⁶⁾. The decision of the Canadian Defence Research Board to explode very large amounts of high explosive provided a medium for a variety of target-response trials that was welcome at a time when nuclear tests in Australia were suspended. A.W.R.E. used the 100-ton explosion in 1961 to test, among other items, the model length of the London tube, at $\frac{1}{40}$ th scale, that had already been tested at $\frac{1}{117}$ scale.

Blast Entry from Stations

There was remarkable agreement with the $\frac{1}{117}$ th scale trials: "maximum overpressure in the train tunnels was of the order of $\frac{1}{3}$ rd the corresponding peak shock overpressure in the incident blast. The pressures in the stations were about $\frac{1}{6}$ th those in the corresponding incident blast". In comparing the results at the two scales it was noted that the pressures in the train tunnels (between stations) was higher at Suffield than at the smaller scale; this may, the report suggests, have been due to some blast entry from the crater at Suffield.

Blast Entry from the Crater

There may - as has just been noted - have been some entry of blast at the crater. But the all-important fact is that it was nowhere enough to bring the pressure in the tunnel up to more than a $\frac{1}{3}$ rd of the free-air pressure (see fig. 30 reproduced, and attached to this note.) From this, and from a detailed study of tunnel rings ejected by the explosion over a wide area, it can be concluded that the instantaneous crushing of the tube near the crater sealed it against the entry of any significant blast pressure.

Air Flow in Stations

The Report indicates that there would be turbulence generated by blast entry at stations and that there would be a danger to occupants there, on account of blast "windage" acting on them and on missiles that could injure them. This danger would be less in the train tunnels between stations.

Conclusion

The Advisory Group discussed the Suffield Test on tunnels on Nov. 1st 1962, and concluded that model experiments have successfully demonstrated that the risks from blast inside the London tubes would be less than above ground. The Group considered that the results obtained were consistent enough to provide as good an estimate of full-scale effects from megaton weapons as was likely to be obtainable, and that the Chairman could advise the Home Office confidently on the basis of these results. The Group accepted that there would be a risk of casualty-producing air flow in stations, but decided to defer a decision on whether further research on this problem would be profitable. The Chairman said that he would first convey the results of the completed research to the Shelter Division of the Home Office before asking the Group whether it was worth studying this remaining, but less important, problem.

3rd October, 1963.

References

- (1) Advisory Group on Structural Research for Civil Defence
Note by Chairman on the Structural Research Programme for Shelters. SAB/SG(57)6. (Restricted)
- (2) Notes of Meeting on 15th May 1957. SAB/SG(57)2nd Minutes
(Confidential)
- (3) The Entry of Air Blast from Craters into Tunnels. A.W.R.E.
Report E1/59 (Official Use Only)
- (4) The Effect of Tunnel Blockage on Shock Waves SAB/SG(58)6
(Confidential)
- (5) Model Experiments on the Entry of Blast into the London Underground System, Interim Report on Rounds 1 and 2. SAB/SG(59)4
(Confidential)
- (6) ¹/40th Scale Experiment to Assess the Effect of Nuclear Blast on the London Underground System. A.W.R.E. Report E2/62.
(Official Use Only.)

Proceedings of the Symposium

held at Washington, D. C.

April 19-23, 1965 by the

Subcommittee on Protective Structures,

Advisory Committee on Civil Defense,

National Academy of Sciences—

National Research Council

Protective Structures for

CIVILIAN POPULATIONS

1966

MODEL ANALYSIS

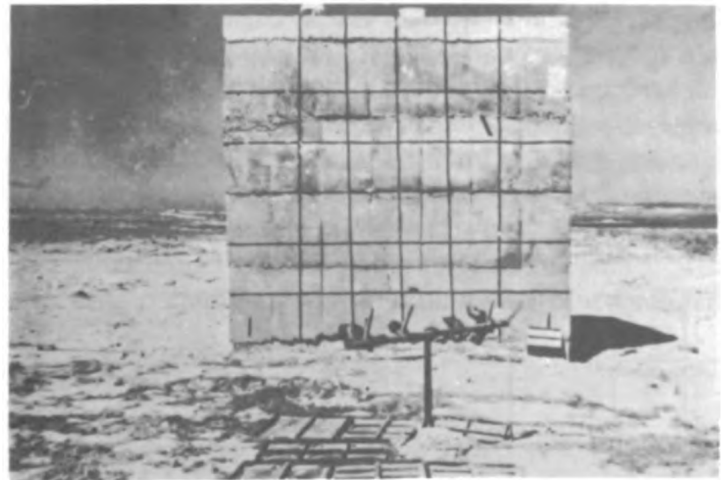
Mr. Ivor Ll. DAVIES
Suffield Experimental Station
Canadian Defense Research Board
Ralston, Alberta, Canada

Nuclear-Weapon Tests

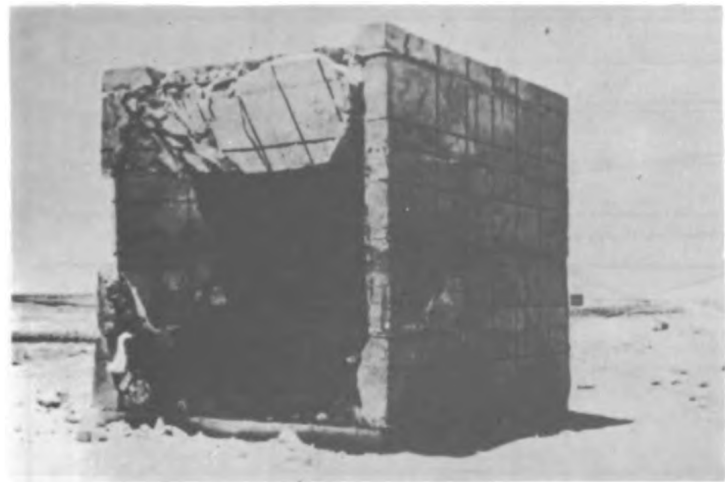
In 1952 we fired our first nuclear device, effectively a "nominal" weapon, at Monte Bello, off north-west Australia. To the blast loading from this weapon we exposed a number of reinforced-concrete cubicle structures that had been designed for the dynamic loading conditions, and for which we made the best analysis of response we were competent to make at that time. Our estimates of effects were really a dismal failure. The structures were placed at pressure levels of 30, 10, and 6 psi, where we expected them to be destroyed, heavily damaged with some petaling of the front face, and extensively cracked, respectively. In fact, the front face of the cubicle at 30 psi was broken inwards; failure had occurred along both diagonals, and the four triangular petals had been pushed in. At the 10-psi level, where we had three cubicles, each with a different wall thickness (6, 9, and 12 in.), we observed only light cracking in the front face of that cubicle with the least thick wall (6 in.). The other two structures were apparently undamaged, as was the single structure at the 6-psi level.

In 1957, the first proposals were made for the construction of the underground car park in Hyde Park in London. The Home Office was interested in this project since, in an emergency, the structure could be used as a shelter. Consequently a request was made to us at Atomic Weapons Research Establishment (A.W.R.E.) to design a structure that would be resistant to a blast loading of about 50 psi, and to test our design on the model scale.

Using the various load-deformation curves obtained in this test, an estimate was made of the response of the structure to blast loading. Of particular interest was the possible effect of 100 tons of TNT, the first 100-ton trial at Suffield in Alberta.



10 p.s.i.



34 p.s.i.

Dynamic tests, Monte Bello cubicles.

A total of seven more models was made; six were shipped to Canada and placed with the top surface of the roof flush with the ground and at positions where peak pressures of 100, 80, 70, 60, 50, and 40 psi were expected. The seventh model was kept in England for static testing at about the time of firing. The results were not as expected. In the field, the four models farthest from the charge were apparently undamaged; we could see no cracking with the eye, nor did soaking the models with water reveal more than a few hair cracks. The model nearest the charge was lightly cracked in the roof panels and beams, and one of the columns showed slight spalling at the head. This model had been exposed to a peak pressure of 110 psi.

THE PROTECTION AGAINST FALLOUT RADIATION AFFORDED BY CORE SHELTERS IN A TYPICAL BRITISH HOUSE

Daniel T. Jones
Scientific Adviser, Home Office, London

Protective Factors in a Sample of British Houses (Windows Blocked)

Protective Factor	Percentage of Houses
< 25	36%
25-39	28%
40-100	29%
> 100	7%

"A very much improved protection could be obtained by constructing a shelter core. This means a small, thick-walled shelter built preferably inside the fallout room itself, in which to spend the first critical hours when the radiation from fallout would be most dangerous."⁽¹⁾

The full-scale experiments were carried out at the Civil Defense School at Falfield Park.⁽²⁾

In the staircase construction, the shelter consisted of the cupboard under the stairs, sandbags being placed on treads above and at the sides.

A 93 curies cobalt-60 source was used.

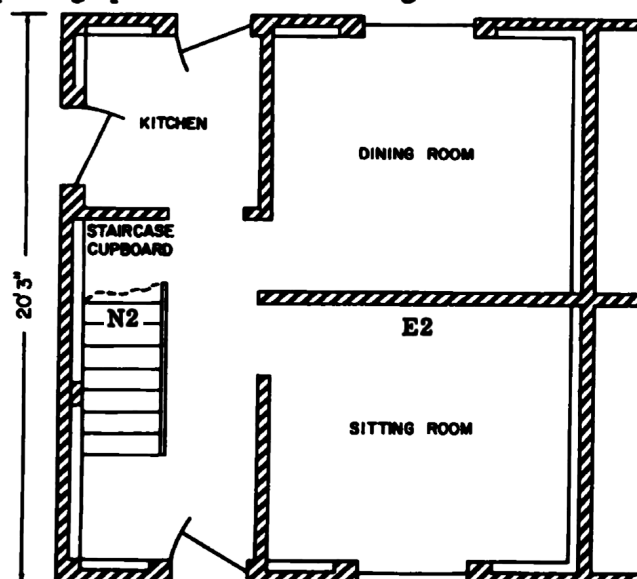
9 in. brick walls The windows and doors were not blocked		contribution r/hr/c/ft ²	Protective Factor	
	Position	Ground	Roof	
House only	E2	15.0	8.4	21
Lean-to	E2	10.4	2.4	39
Staircase cupboard:				
Stairs only sandbagged	N2	29.2	5.3	14
Stairs and outer wall sandbagged	N2	16.4	4.6	24
Stairs, outer wall, kitchen wall and corridor partition sandbagged	N2	8.8	1.8	47

1. Civil Defence Handbook No. 10, HMSO, 1963.
2. Perryman, A. D., Home Office Report CD/SA 117.

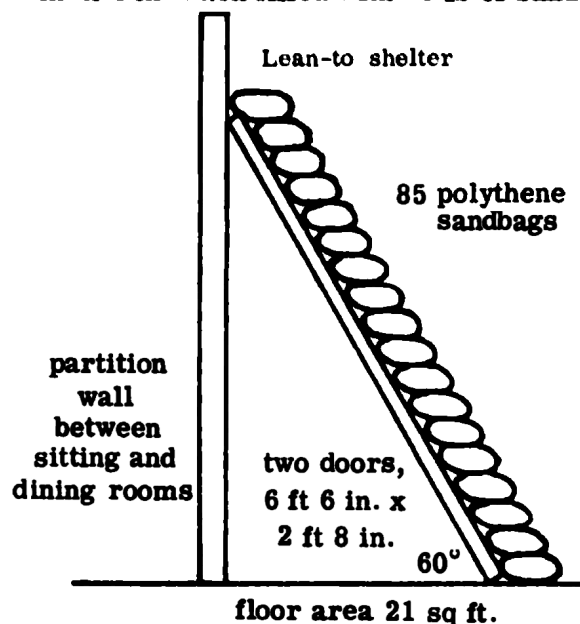
1. Six sandbags per tread, and a double layer on the small top landing. 96 sandbags were used.

2. As (1), together with a 4-ft-high wall of sandbags along the external north wall. 160 sandbags were used.

3. As (2), together with 4-ft-high walls of sandbags along the kitchen/cupboard partition wall and along the passage partition. 220 sandbags were used.



sandbags 24 in. x 12 in. when empty; 16 in. x 9 in. x 4 in. when filled with 25 lb of sand.



BLAST AND OTHER THREATS

Harold Brode
The RAND Corporation, Santa Monica, California

Chemical High-Explosive Weapons

As in past aerial warfare, bombs and missiles carrying chemical explosives to targets are capable of extensive damage only when delivered in large numbers and with high accuracy.

Biological Warfare

Most biological agents are inexpensive to produce; their effective dissemination over hostile territories remains the chief deterrent to their effective employment. Twenty square miles is about the area that can be effectively covered by a single aircraft; large area coverage presents a task for vast fleets of fairly vulnerable planes flying tight patterns at modest or low altitudes. While agents vary in virulence and in their biologic decay rate, most are quite perishable in normal open-air environments. Since shelter and simple prophylactic measures can be quite effective against biological agents, there is less likelihood of the use of biological warfare on a wholesale basis against a nation, and more chance of limited employment on population concentrations—perhaps by covert delivery, since shelters with adequate filtering could insure rather complete protection to those inside.

Chemical Weapons

Chemical weapons, like biological weapons, are relatively inexpensive to create, but face nearly insurmountable logistics problems on delivery. Although chemical agents produce casualties more rapidly, the greater amounts of material to deliver seriously limit the likelihood of their large-scale deployment. Furthermore, chemical research does not hold promise of the development of significantly more toxic chemicals for future use.

Radiological Weapons

The advantages of such modifications are much less real than apparent. In all weapons delivered by missiles, minimizing the payload and total weight is very important. If the total payload is not to be increased, then the inclusion of inert material to be activated by neutrons must lead to reductions in the explosive yield. If all the weight is devoted to nuclear explosives, then more fission-fragment activity can be created, and it is the net difference in activity that must be balanced against the loss of explosive yield. As it turns out, a fission explosion is a most efficient generator of activity, and greater total doses are not achieved by injecting special inert materials to be activated.

Perret, W.R., Ground Motion Studies at High Incident Overpressure, The Sandia Corporation, Operation PLUMBBOB, WT-1405, for Defense Atomic Support Agency Field Command, June 1960.

The Neutron Bomb

The neutron bomb, so called because of the deliberate effort to maximize the effectiveness of the neutrons, would necessarily be limited to rather small yields—yields at which the neutron absorption in air does not reduce the doses to a point at which blast and thermal effects are dominant. The use of small yields against large-area targets again runs into the delivery problems faced by chemical agents and explosives, and larger yields in fewer packages pose a less stringent problem for delivery systems in most applications. In the unlikely event that an enemy desired to minimize blast and thermal damage and to create little local fallout but still kill the populace, it would be necessary to use large numbers of carefully placed neutron-producing weapons burst high enough to avoid blast damage on the ground, but low enough to get the neutrons down. In this case, however, adequate radiation shielding for the people would leave the city unscathed and demonstrate the attack to be futile.

The thermal radiation from a surface burst is expected to be less than half of that from an air burst, both because the radiating fireball surface is truncated and because the hot interior is partially quenched by the megatons of injected crater material.

SUPERSEISMIC GROUND-SHOCK MAXIMA (AT 5-FT DEPTH)

Vertical acceleration: $\alpha_{vm} \approx 340 \Delta P_g / C_L \pm 30$ per cent. Here acceleration is measured in g's and overpressure (ΔP_g) in pounds per square inch. An empirical refinement requires C_L to be defined as the seismic velocity (in feet per second) for rock, but as three fourths of the seismic velocity for soil.

OUTRUNNING GROUND-SHOCK MAXIMA (AT ~10-FT DEPTH)

Vertical acceleration: $\alpha_{vm} \approx 2 \times 10^5 / C_L r^2$ + factor 4 or -factor 2. Acceleration is measured in g's, and r is the scaled radial distance—i.e., $r = R/W^{1/3}$ kft/(mt)^{1/3}.

Data taken on a low air-burst shot in Nevada indicate an exponential decay of maximum displacement with depth. For the particular case of a burst of ~40 kt at 700 ft, some measurements were made as deep as 200 ft below the surface of Frenchman Flat, a dry lake bed, which led to the following approximate decay law, according to Perret.

$$\delta = \delta_0 \exp(-0.017D),$$

where δ represents the maximum vertical displacement induced at depth D , δ_0 is the maximum displacement at the surface, and D is the depth in feet.

Foreword

If the country were ever faced with an immediate threat of nuclear war, a copy of this booklet would be distributed to every household as part of a public information campaign which would include announcements on television and radio and in the press. The booklet has been designed for free and general distribution in that event. It is being placed on sale now for those who wish to know what they would be advised to do at such a time.

May 1980



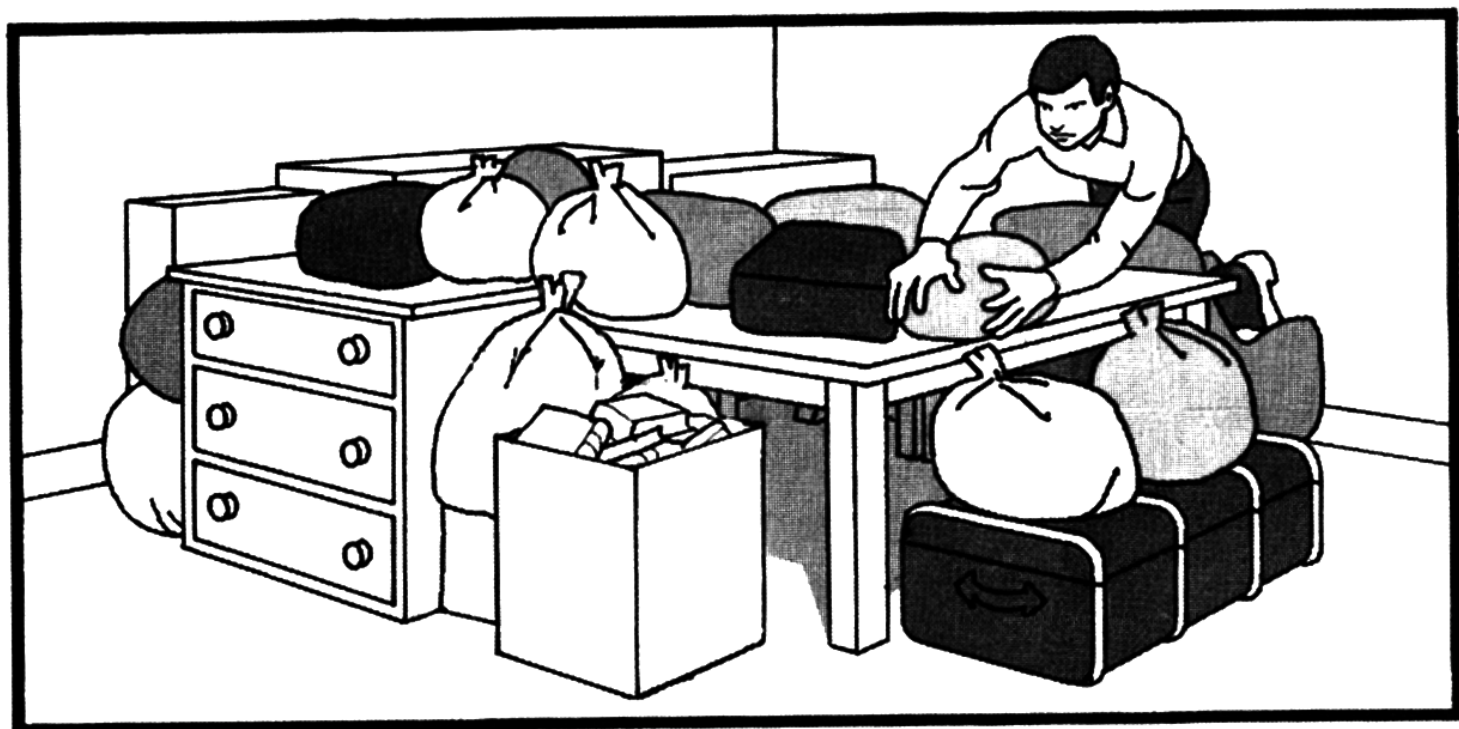
Protect and Survive
ISBN 0 11 3407289

If Britain is attacked by nuclear bombs or by missiles, we do not know what targets will be chosen or how severe the assault will be.

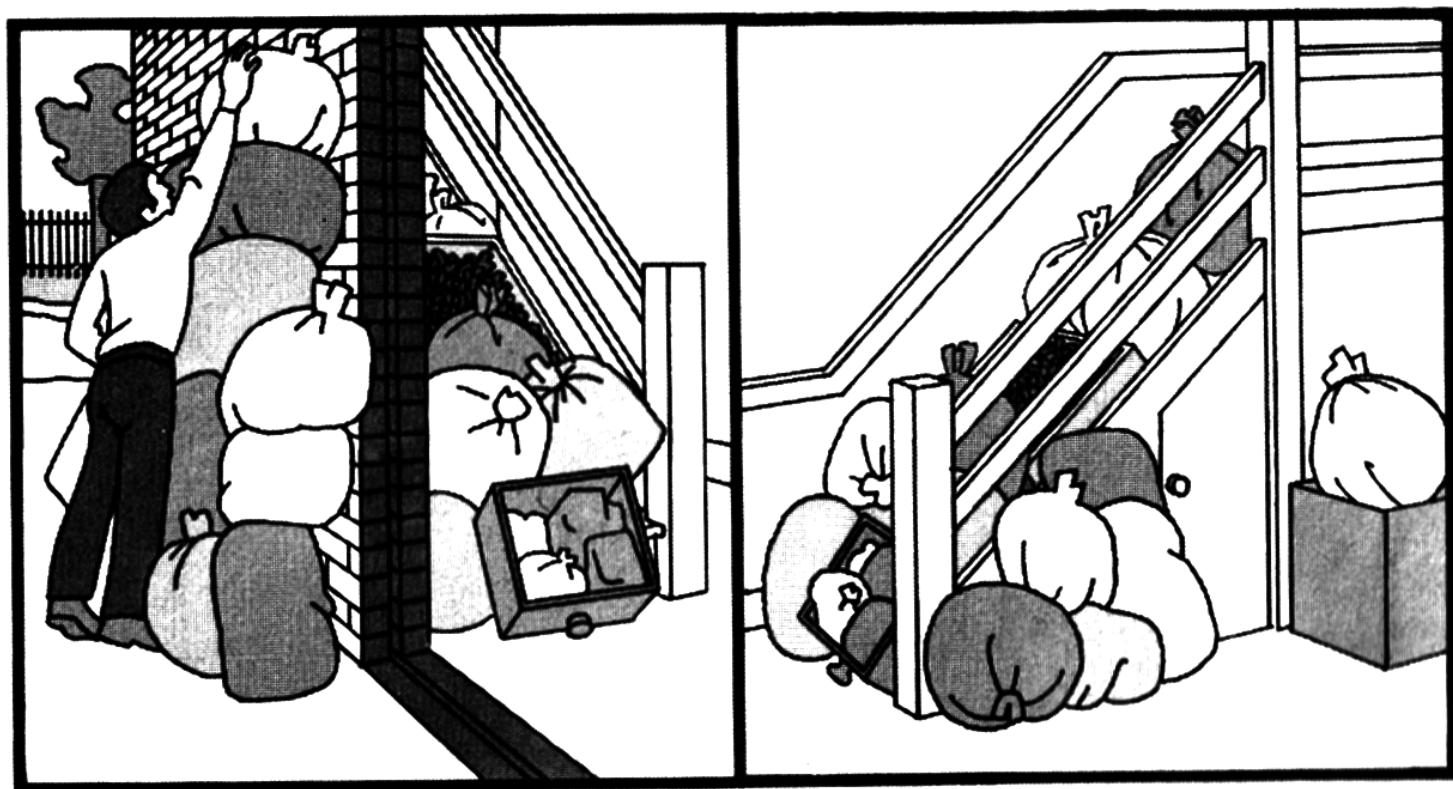
If nuclear weapons are used on a large scale, those of us living in the country areas might be exposed to as great a risk as those in the towns. The radioactive dust, falling where the wind blows it, will bring the most widespread dangers of all. No part of the United Kingdom can be considered safe from both the direct effects of the weapons and the resultant fall-out.

The dangers which you and your family will face in this situation can be reduced if you do as this booklet describes.

Use tables if they are large enough to provide you all with shelter. Surround them and cover them with heavy furniture filled with sand, earth, books or clothing.



Use the cupboard under the stairs if it is in your fall-out room. Put bags of earth or sand on the stairs and along the wall of the cupboard. If the stairs are on an outside wall, strengthen the wall outside in the same way to a height of six feet.



What to do after the Attack:

After a nuclear attack, there will be a short period before fall-out starts to descend. Use this time to do essential tasks. This is what you should do.

Do not smoke.

Check that gas, electricity and other fuel supplies and all pilot lights *are* turned off.

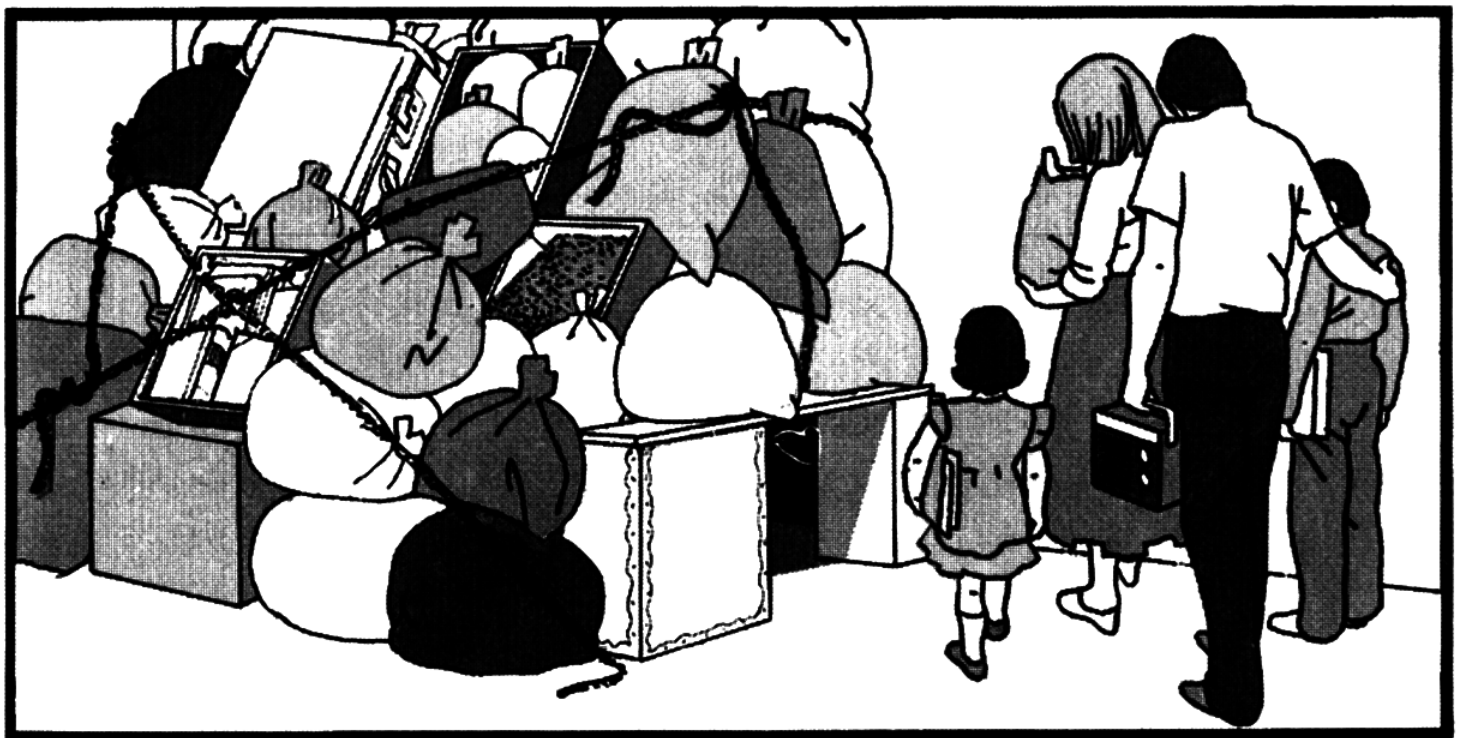
Go round the house and put out any small fires using mains water if you can.

If anyone's clothing catches fire, lay them on the floor and roll them in a blanket, rug or thick coat.



If there is structural damage from the attack you may have some time before a fall-out warning to do minor jobs to keep out the weather – using curtains or sheets to cover broken windows or holes.

If you are out of doors, take the nearest and best available cover as quickly as possible, wiping all the dust you can from your skin and clothing at the entrance to the building in which you shelter.



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SEPTEMBER 1964

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CD/SA 121

IGNITION AND FIRE SPREAD IN URBAN AREAS FOLLOWING A NUCLEAR ATTACK

G. R. Stanbury

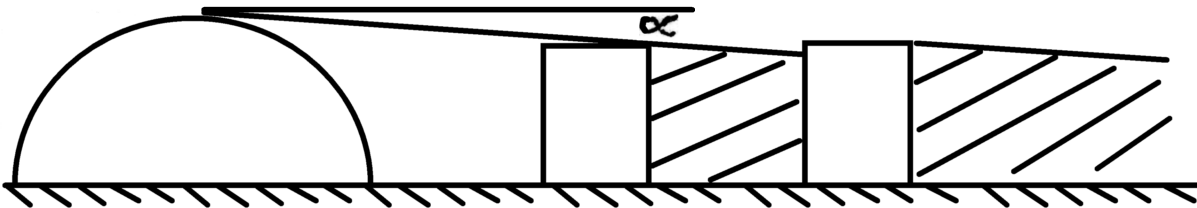
INITIAL FIRE INCIDENCE

For a 1 MT groundburst bomb the height of the top of the fireball above ground is about 0.72 miles. Because this distance is large compared with the height of most buildings, the exposed upper floors do actually see a large part of the fireball and not just the top of it, but in assuming that the radiation is just as intense from the top as from the middle we were overestimating the fire risk.

On the above basis the following table gives the number of exposed upper floors (to the nearest $\frac{1}{2}$ floor) for a range of distances from the explosion and a range of street widths.

Effect of Shielding: Estimation of the number of exposed floors

Assuming that buildings on opposite sides of a street which is receiving heat radiation from a direction perpendicular to its length are of the same height



Distance from explosion miles	Angle of arrival α°	$\tan \alpha$	Width of street (units of 10 ft.)						
			2	3	4	5	6	7	8
1	35	.72	1.5	2	3	3.5	4.5	5	6
$1\frac{1}{2}$	26	.48	1	1.5	2	2.5	3	3.5	4
2	20	.36	.5	1	1.5	2	2	2.5	3
3	$13\frac{1}{2}$	.24	.5	.5	1	1	1.5	1.5	2
4	10	.18	.5	.5	.5	1	1	1.5	1.5
5	8	.15	.5	.5	.5	.5	1	1	1

we take the average depth of a floor to be 10 ft.

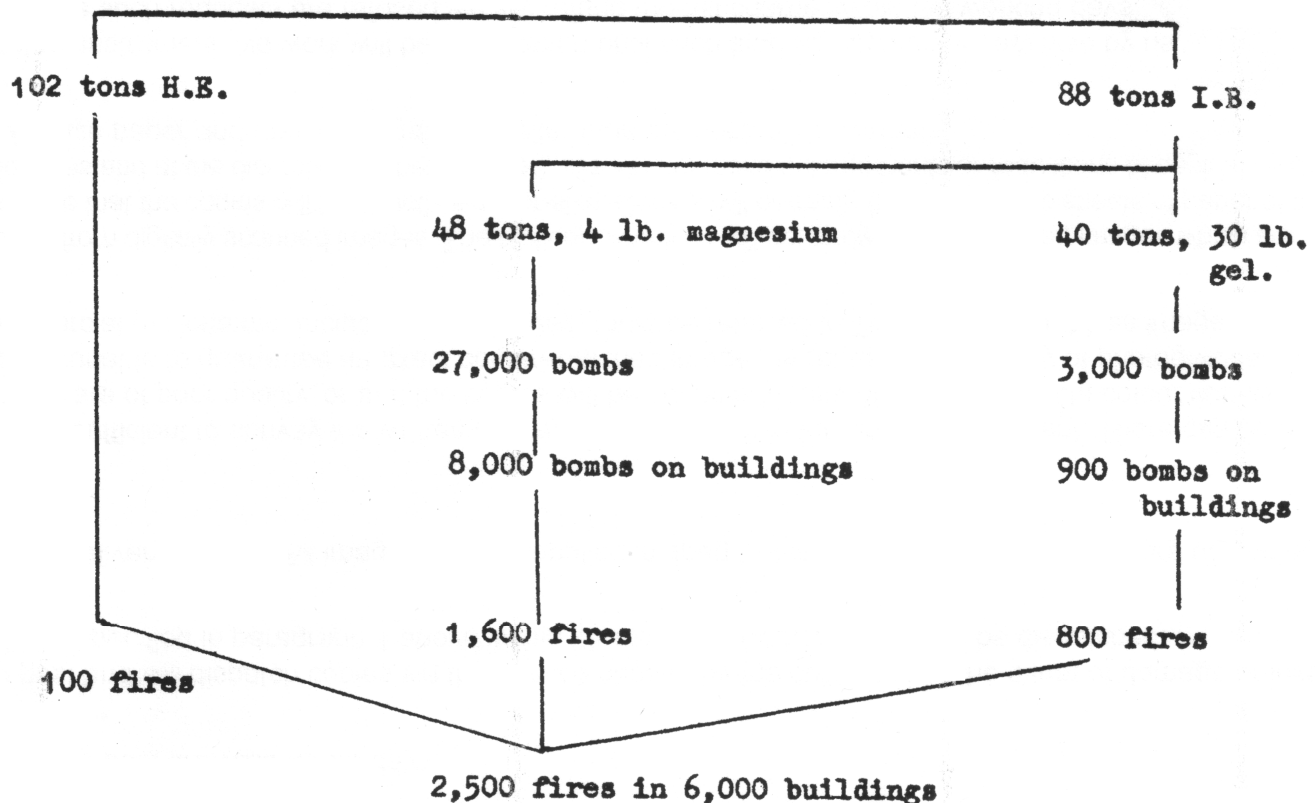
Angle between heat flash and street (degrees)	90-75	75-60	60-45	45-30	30-15	15-0
Proportion of heat flash entering windows %	99	92.5	80	60	40	14

SPREAD OF FIRE

From last war experience of mass fire raids in Germany it was concluded that the overall spread factor was about 2; i.e. about twice as many buildings were destroyed by fire as were actually set alight by incendiary bombs

Number of fires started per square mile in the fire-storm raid on Hamburg, 27th/28th July, 1943

Bombs dropped



However, the important thing to note is that the total number of fires started in each square mile (2,500) was nearly half that of the total number of buildings; in other words, almost every other building was set on fire during the raid itself. When this happened no fire-fighting organisation, however efficient could hope to prevent the fires from joining together and engulfing the whole area.

When the figure of 1 in 2 for the German fire storms is compared with the figures for initial fire incidence of ~ 1 in 15 to 30 obtained in the Birmingham and Liverpool studies it can only be concluded that a nuclear explosion could not possibly produce a fire storm.

Fire situation from 1,499 fly bombs in the built-up
part of the London Region

WWII VI high explosives (1 ton TNT warhead) (cruise missiles)

Where dropped	Number of fly bombs	Fly Bombs Caused				
		No fire	Small fire	Medium fire	Serious fire	Major fire
City	119 199	47	49	17	4	2
West-End	33	8	22	2	-	1
Closed Residential	430	207	203	20	-	-
Open Residential	804	478	296	28	2	-
Docks	113	64	39	8	1	1
Grand Totals	1,499	804	609	75	7	4

Discussion of results

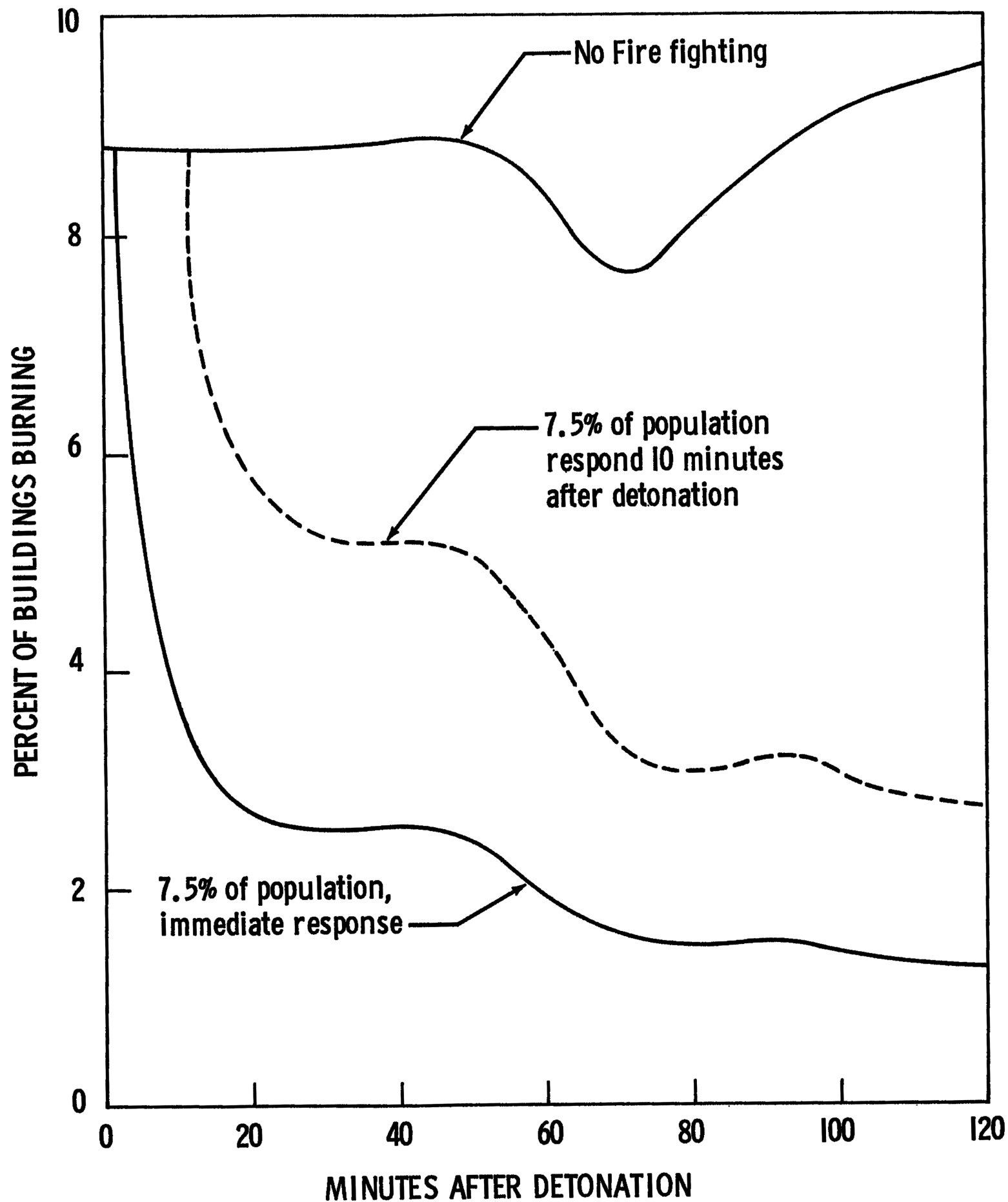
Two important points emerge from a study of these results:-

- (i) The small proportion of fly bombs - less than 20% - which started fires of any greater category than "small" even in the most heavily built-up areas; and
- (ii) The large proportion which started no fires at all even in the most heavily built-up areas.

All these fly bombs fell in the summer months of 1944 which were unusually dry. In winter in this country in residential areas there are many open fires which may provide extra sources of ignition. The domestic occupancy is a low fire risk however, and as the proportion of such property in the important City and West End areas is small this should not introduce any serious error. Moreover, in winter, the high atmospheric humidity and the correspondingly high moisture content of timber would tend to retard or even prevent the growth of fire.

In order to determine how many fly bombs are equivalent to one nominal atomic bomb one method is to compare the areas over which a given category of house damage is produced by each. If we do this for a $\frac{3}{8}$ th mile air burst as at Hiroshima, the result is that 1 atomic bomb does as much damage as about 1,200 fly bombs.

This in itself is not a serious fire situation and it is doubtful whether it could ever give rise to a fire storm. In Hamburg 2,500 fires were started per square mile by a bomb density (combined H.E. and I.B.) of 200 tons per square mile, and for the area of destruction produced by an atomic bomb this would correspond to a total of about 10,000 fires.



HOME OFFICE
SCOTTISH HOME DEPARTMENT

MANUAL OF CIVIL DEFENCE

Volume I

PAMPHLET No. 1

NUCLEAR WEAPONS

LONDON
HER MAJESTY'S STATIONERY OFFICE
1956

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- 30 Research into the causes of fire in Hiroshima and Nagasaki, combined with a study of the secondary fire risk from the flying bomb damage in this country during the last war has shown that with nuclear attack the secondary fire risk is likely to be small compared with the primary risk of direct ignition by thermal radiation.

Fire precautions

- 31 Although the fire risk even from a nominal bomb is always serious, targets in this country, where the great majority of buildings are of brick, stone or concrete, are less vulnerable to fire than were those in Japan, where most of the buildings were of wood. Moreover, if people do what they can to keep heat radiation out of buildings, the risk of fire can be further reduced, although these precautions would be effective only beyond the central area of blast destruction (see Chapter IV).
- 32 It might be advisable to brick up certain windows of important buildings, but since the thermal radiation has no great penetrating power, any opaque screen, especially a white one, will keep it out: the simple process of whitewashing windows will keep out about 80 per cent. of the heat. The windows may be broken by the blast wave but as this travels more slowly it arrives after the thermal radiation is over (except of course in the central area of blast destruction), whether the bomb is a hydrogen bomb or an atomic bomb.
- 33 Another obvious fire precaution is the removal of all readily combustible material from the direct path of any heat radiation that could possibly enter windows or other openings.
- 34 Both these precautions apply only to those windows and other openings that have a direct view of some part of the sky. In a built-up area they would apply more particularly to the windows of upper floors; even for a high airburst, in a closely built-up area one building shields another to a considerable extent.

The probable fire situation in a British city

- 35 Within $\frac{1}{2}$ mile of an airburst nominal bomb the heat flash is very intense indeed, but in this area there would be almost complete destruction of buildings by blast, and this would tend to impede the development of fire. This did not happen in Japan because most Japanese houses are constructed of wood and once they were set on fire they continued to burn even when knocked over. In this country only about 10 per cent. of all the material in the average house is combustible, and under conditions of complete collapse, where air would be almost entirely excluded, it is doubtful whether a fire could continue on any vigorous scale. The main fire zone will be around this central area of heavy destruction, in the region where buildings are damaged but standing sufficiently to allow free burning. For a nominal bomb, this zone is likely to reach as far as $1\frac{1}{4}$ miles.
- 36 The range of ignition is affected to some extent by the state of the atmosphere and on a dull misty day will be reduced, although it is impossible to say precisely to what degree.

The possibilities of a fire storm

- 37 The chief feature of a fire storm is the generation of high winds which are drawn into the centre of the fire area to feed the rising column of hot air and flames. These in-rushing winds prevent the spread of fire outwards, but ensure the almost complete destruction by fire of

everything within the fire area. This inevitably increases the number of casualties, since it becomes impossible for people to escape by their own efforts because they succumb to the effects of suffocation and heat stroke.

- 38 The Hiroshima bomb (but not the Nagasaki one) caused a fire storm. A fire storm occurred in Hamburg and possibly also in several other German cities as a result of accurate and very dense attacks with incendiary and high explosive bombs by the R.A.F. Information on the subject is limited, but it has been fairly well established that during these particular raids on Germany half the buildings in the target area were set on fire in about half an hour. In such circumstances it seems that nothing can prevent all the fires from joining together into one mass fire engulfing the whole area.
- 39 Whether a fire storm develops depends also on the nature of the target; where there are tall buildings closely packed together with plenty of combustible material to burn, the risk is much greater than in areas less densely built up.
- 40 It seems unlikely from the evidence available that an initial density of fires equivalent to one in every other building would be started by a nuclear explosion over a British city. Studies have shown that a much smaller proportion of buildings than this would be exposed to thermal radiation and even then it is not certain that continuing fires would develop. Curtains may catch fire, but it does not necessarily follow that they will set light to the room; in the last war it was found that only one incendiary bomb out of every six that hit buildings started a continuing fire. Moreover after a nuclear explosion the large and almost completely flattened central area would counteract the development of a fire storm, since one essential requirement seems to be a continuous mass of fire over a large area. It is unlikely, therefore, that a fire storm would develop after a nuclear attack on a British city, though the possibility cannot be ruled out. The risk can be reduced by clearing or partially clearing the top floors of buildings which are likely to be exposed to the heat radiation, and by adopting the other precautions mentioned above.
- 41 There would, however, in any case be many serious fires and fire areas.

Scaling laws

- 42 For more powerful bombs the total heat output is roughly proportional to the power of the bomb, so that a 10 megaton bomb, which is 500 times more powerful than a nominal bomb, radiates 500 times as much heat. Because of the inverse square law, the distance at which a given amount of heat is received (measured per unit area of receiving surface) varies as the square root of the power of the bomb. For example, if a nominal airburst bomb produces 5 calories per square centimetre at 1 mile, a 10 megaton airburst bomb will produce the same amount at 22 miles ($22 = \sqrt{500}$). However, although at 1 mile from a nominal bomb an intensity of 5 calories per square centimetre would ignite easily combustible materials and start fires, it would not do so at 22 miles from a 10 megaton bomb because the heat is applied more slowly. From a 10 megaton bomb, with its longer lasting thermal radiation (see paragraph 21), it takes about 20 calories per square centimetre to start fires because so much of the heat (spread out over the longer emission) is wasted by conduction into the interior of the combustible material and by convection and re-radiation whilst the

temperature of the surface is being raised to the ignition point. But the distance at which 20 calories per square centimetre can be produced is only 11 miles, so that the scaling factor for a 10 megaton airburst bomb is therefore 11 and not 22.

- 43 For a ground burst bomb, however, several other factors contribute to a further reduction in the fire range. Apart from an actual loss of heat by absorption into the ground and from the pronounced shielding effect of buildings, the debris from the crater tends to reduce the radiating temperature of the fireball and a greater proportion of the energy is consequently radiated in the infra red region of the spectrum—this proportion being more easily absorbed by the atmosphere.

The magnitude of this absorption effect is not known with certainty, but it is important in hydrogen bomb explosions because of the longer ranges involved and because—as later explained in paragraph 81—the likelihood of ground bursts has been increased with the advent of the hydrogen bomb. For all these reasons it has been estimated that the scaling factor for the fire range for a ground burst 10 megaton bomb is about 8. This will mean a fire ring extending from about $3\frac{1}{2}$ to 10 miles instead of, as in the case of a nominal airburst bomb, from $\frac{1}{2}$ to $1\frac{1}{4}$ miles. Isolated fires may occur at greater distances, depending on the combustibility of material within buildings, but it is impossible to apply precise scaling laws to such haphazard incidents.

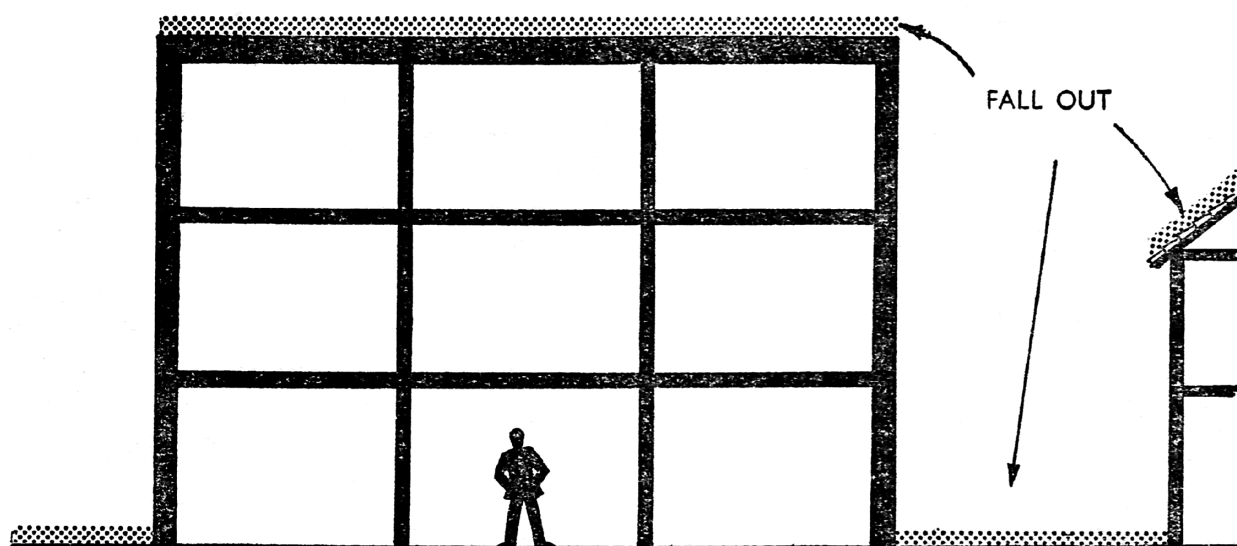
- 44 An important point in relation to personal protection against the effects of hydrogen bomb explosions is that because the thermal radiation lasts so long there is more time for people who may be caught in the open, and who may be well beyond the range of serious danger from blast, to rush to cover and so escape some part of the exposure. For example, people in the open might receive second degree burns (blistering) on exposed skin at a range of 16 miles from a 10 megaton ground burst bomb (8×2 —see paragraph 24). If, however, they could take cover in a few seconds they would escape this damage. Moreover, at this range the blast wave would not arrive for another minute and a half so that any effects due to the blast in the open (e.g. flying glass, etc.) could be completely avoided.

Practical protection

- 88 Large buildings with a number of storeys, especially if they are of heavy construction, provide much better protection than small single-storey structures (see Figure 4). Houses in terraces likewise provide much better protection than isolated houses because of the shielding effect of neighbouring houses.

GOOD PROTECTION

Solidly constructed multi-storeyed building with occupants well removed from fall-out on ground and roof. The thickness of floors and roof overhead, and the shielding effect of other buildings, all help to cut down radiation



BAD PROTECTION

Isolated wooden bungalow

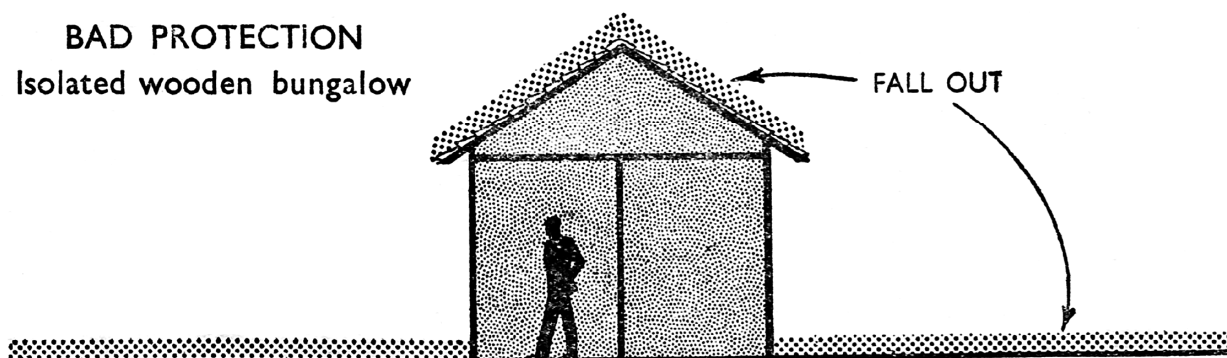


FIGURE 4

Examples of good and bad protection afforded by buildings against fall-out.

- 89 It is estimated that the protection factor (the factor by which the outside dose has to be divided to get the inside dose) of a ground floor room in a two-storey house ranges from 10 to about 50, depending on wall thickness and the shielding afforded by neighbouring buildings. The corresponding figures for bungalows are about 10–20, and for three-storey houses about 15–100. An average two-storey brick house in a built-up area gives a factor of 40, but basements, where the radiation from outside the house is attenuated by a very great thickness of earth, have protection factors ranging up to 200–300. A slit trench with even a light cover of boards or corrugated iron without earth overhead gives a factor of 7, and if 1 ft. of earth cover is added the

factor rises to 100. If the trench can be covered with 2 or 3 feet of earth then a factor of more than 200–300 can be obtained (see Figure 5).

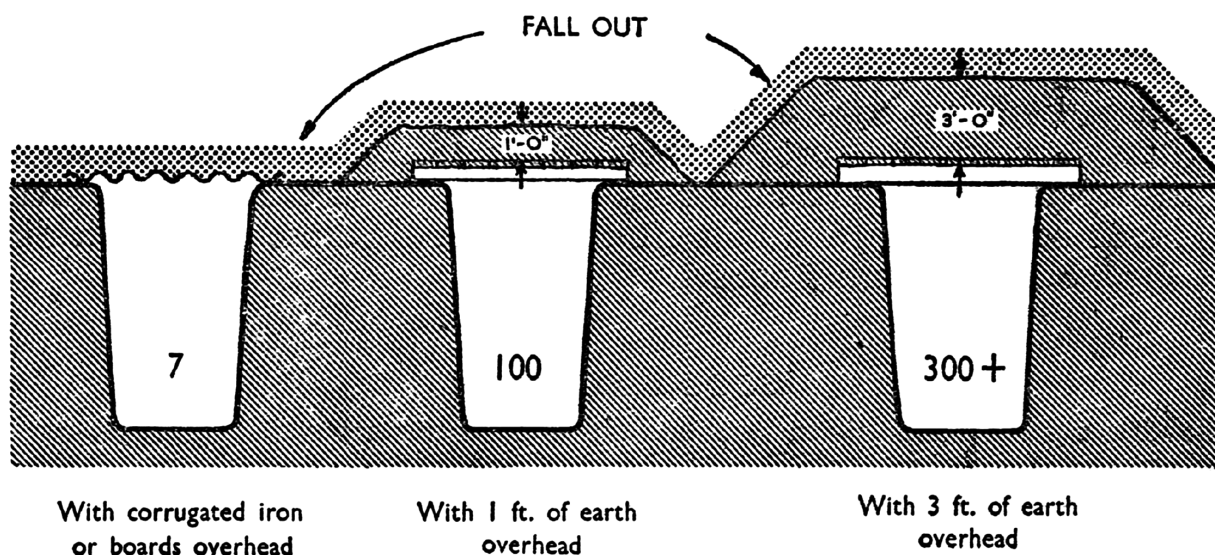


FIGURE 5

Protection factors in slit trenches (the factor by which the outside dose is divided to get the inside dose).

Choosing a refuge room

- 90 In choosing a refuge room in a house one would select a room with a minimum of outside walls and make every effort to improve the protection of such outside walls as there were. In particular the windows would have to be blocked up, e.g. with sandbags. Where possible, boxes of earth could be placed round an outside wall to provide additional protection, and heavy furniture (pianos, bookcases etc.) along the inside of the wall would also help. A cellar would be ideal. Where the ground floor of the house consists of boards and timber joists carried on sleeper walls it may be possible to combine the high protection of the slit trench with some of the comforts of the refuge room by constructing a trench under the floor.

Once a trap door had been cut in the floor boards and joists and the trench had been dug, there would be no further interference with the peace-time use of the room.

Estimated under-cover doses in the fall-out area

- 91 Taking an average protective factor of 40 for a two-storey house in a built-up area, the doses accumulated in 36 hours for the ranges referred to in the U.S. Atomic Energy Commission Report (paragraph 84) would have been:—

190 miles downwind	7½r
160 " "	12½r
140 " "	20r

15 Megatons
Bravo 1954

which are all well below the lowest figure of 25r referred to in Table 1. At closer ranges along the axis of the fall-out, the doses accumulated in 36 hours would have been much higher, but over most of the contaminated area—with this standard of protection—the majority of those affected would have been saved from death, and even from sickness, by taking cover continuously for the first 36 hours.

5. Radiation sickness

Assume dose incurred in a single shift (3–4 hours) by the “average” man, over the whole body:—

25 roentgens	—No obvious harm.
100 ,,	—Some nausea and vomiting.
500 ,,	—Lethal to about 50 per cent. people (death up to 6 weeks later).
800 ,,	or more—Lethal to all (death up to 6 weeks later).

Note: If dose spread uniformly over 2–3 days, then 60 roentgens could be incurred with no more effect than 25 roentgens in a single exposure of 3–4 hours.

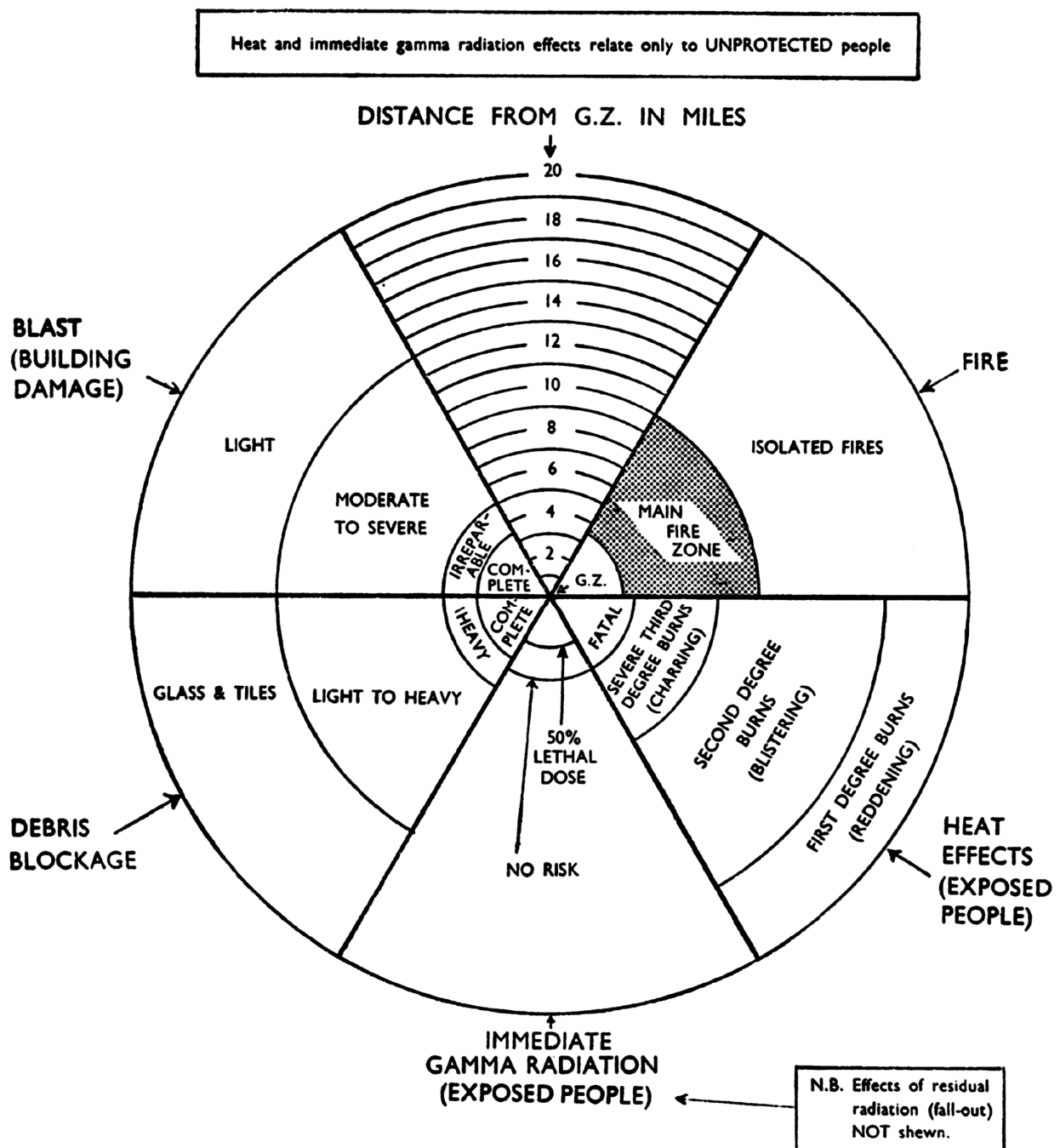


FIGURE 11

Combined effects (excluding residual radioactivity) from a 10 megaton ground burst bomb. Heat and immediate gamma radiation effects relate only to UNPROTECTED people.